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(54) Fast changing heating-cooling method

Verfahren zur schnell wechselnden Heizung und/oder Kühlung

Procédé de chauffage et/ou de refroidissement à variation rapide

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Description

Field of the Invention

[0001] The present invention relates to a method for obtaining fast changes in the temperature of a variable temperature element. More particularly, the invention is directed to a method which permit to cool a given area in the cryogenic range, and to heat the same area to relatively high temperatures, within very short periods of time, and *vice versa*.

Background of the Invention

[0002] The ability to cause fast changes in temperatures, particularly between very low temperatures and room or higher temperatures, on a desired surface and at a desired location, is of practical importance in many uses. Fast temperature changes can be exploited, for instance, in the treatment of various materials, for sealing or surface curing purposes, etc. Cold and hot surfaces are used also for medical uses. For instance, cryogenic techniques are employed to destroy malignant tissues, or for plastic surgery. One example of such a use is presented in SU 774,549, which relates to a thermal treatment of biological tissues by passing heat carriers through a cryosurgical probe. The method is said to be useful in the cryo-surgery of the human brain. This method, however, involves passing a heat carrier through a surgical probe, its subsequent heating and repeated passage through the probe. Acetone or alcohol are used as the heat carrier. Prior to its passage through the probe the heat carrier is either cooled to -70-75°C, or heated to +70-90°C.

[0003] Devices of this type present severe drawbacks, inasmuch as they have long lags in temperature changes, they require cumbersome heating/cooling apparatus outside the probe, and are complicated and expensive to use.

[0004] Cryosurgical instruments having both cry-cooling and heating capabilities are also known in the art. One such device and its medical use have been described by Andrew A. Gage ["Current Issues in Cryosurgery", *Cryobiology* **19**, 219-222(1982), at pp. 220-21]. The device described therein was cooled by liquid nitrogen and electrically heated, to provide hemostasis. The electrical heating, however, by its nature is a relatively slow procedure.

[0005] Another device is described in SU 1,217,377, which exploits the expansion of gases through an orifice. However, simple expansion of gas through an orifice provides relatively slow temperature changes, and the changes in temperature are relatively mild. Thus, for instance, in the device of SU 1,217,377 it is not possible to liquify nitrogen. Additionally, this prior art device employs helium at room temperature which, expanding from a pressure of about 300 atmospheres, will attain a heating of merely about 30°C. In any case, in the single pass expansion described in this reference, liquefaction of nitrogen cannot be achieved. However, helium has an inversion temperature of about 45K, which renders it possible to employ neon or hydrogen as the second gas, as is done in this reference. The highest inversion temperature of neon is about 200K, and of hydrogen is about 180K. Accordingly, these gases cannot be used while using nitrogen as the first gas, because the temperature of liquid nitrogen is 80K, and thus the heating obtainable with neon and hydrogen is low. Additionally, neon and hydrogen may be found at an inversion temperature lower than their maximal temperature, so that no heating is obtained. However, neon is expensive and hydrogen is dangerous, and the obtainable temperatures are unsatisfactory for many uses, which accounts for the lack of success of the above-mentioned device.

[0006] To partly overcome these limitations FR-A-2477406 discloses a cryosurgical probe, cooled by expansion of a refrigerating fluid, such as N_2O, through an orifice, which probe includes a heat exchanger where the fluid in input to the probe, before expansion is cooled by thermal exchange with the fluid already expanded through the orifice.

[0007] In FR-A-2482445 it is further proposed to provide the cryosurgical probe above mentioned with reheating means which may consist, inter alia, of the supply to the probe of a gas which heats when expanded, such as helium or neon.

[0008] However the reference fails to consider that cooling or heating on expansion depends on gas temperature at which expansion occurs and fails to establish any relation between cooling and heating gases to be used in order to achieve fast temperature changes. Prior art devices and methods have so far failed to provide simple and effective fast temperature changing means which can be used in order to exploit the potential of cryogenic techniques, in industry and in medicine. It is therefore clear that it would be highly desirable to be able to exploit such methods in as many as possible applications.

Summary of the Invention

[0009] It is an object of the present invention to provide a method by means of which a fast and periodic change of surface temperature, even down to cryogenic range, can be created, at the desired location, in a simple and effective manner.

[0010] This object is attained by a method as recited in claims 1 to 4.

[0011] Other objectives of the invention will become apparent as the description proceeds.

[0012] The method for creating a surface having a fast changing temperature, according to the invention, comprises providing a heat exchanger coupled to an orifice opening into a jacket which is in contact with the surface to be heated and cooled, the said jacket forming

a reservoir capable of housing a fluid in contact with the surface to be heated and cooled, and providing two gas sources, each gas source being independently connected to the said heat exchanger, one source providing a first gas, which liquefies when it expands through the said orifice, and the other gas source providing a second gas, having an inversion temperature lower than the temperature obtained by the liquefaction of the first gas, and causing the exhaust gas flowing out from the said jacket, to flow through the said heat-exchanger to preheat or precool the inflowing gas, as the case may be, and further causing the said first and the said second gas alternately to flow through the said heat exchanger and orifice, to cool or to heat the said surface with a plurality of heating-cooling cycles; means being provided for allowing and stopping the flow of each gas through the said orifice.

[0013] The selection of appropriate gases to be used in the invention is crucial. For instance, the maximum inversion temperature of helium is 43K. Thus, even when somewhat precooled by boiling nitrogen at 77.3K, it still will warm up when undergoing Joule-Thomson expansion. Furthermore, providing a preheating or precooling of the inflowing gas is not just a matter of efficiency or saving, but is an essential part of the invention, since processes and devices employing a one-pass heating or cooling, without utilizing an exchange of heat via an appropriate heat-exchanger, will not provide sufficiently low or sufficiently high temperatures, and will result in a temperature change which is excessively slow. As stated, the fast change from one extreme temperature to the other is an essential feature of the invention.

[0014] Heat exchangers can be of any type, and may be, e.g., a finned tube heat-exchanger of a porous-matrix heat-exchanger, e.g., of the type described in British Patent No. 1,422,445. The device described in this British patent provides only for the cryocooling of the probe, the purpose being to maintain the temperature of the probe below -80°C, thus avoiding altogether the need for heating the probe. It should be mentioned that, according to the teachings of this patent, heating was necessary, when operating at temperatures above -80°C, for the purpose to prevent the probe from sticking to the tissue. However, when operating according to the invention, with fast cooling-heating cycles, the heat exchanger can be utilized also for heating purposes.

[0015] In one preferred embodiment of the invention, the fast change in temperature is periodic. In another preferred embodiment of the invention the fast change is controlled and effected at the time selected by the operator.

[0016] According to a preferred embodiment of the invention, the first gas is selected from the group consisting essentially of argon, nitrogen, air, krypton, CF_4, xenon and N_2O, and the second gas is helium.

[0017] Cryogenic liquefaction occurs at the tip of the cold extremity of the device operating according to the invention as will be more fully explained hereinafter, under the cooled metal surface. The Linde-Hampson method is applied, using the Joule-Thomson effect for cooldown to liquefaction.

[0018] It should furthermore be understood that for some uses it is important to obtain a high frequency of temperature change, while it is less important to reach extreme temperatures. Thus, for instance, one may which, for a given application, to oscillate between temperatures of -50°C and +100°C only. As will be understood by the skilled person, limiting the upper and/or the lower limit of the desired temperature permits to oscillate between them much more quickly, and the invention also comprises providing such quick oscillations with non-extreme and non cryogenic temperatures. Of course, the skilled engineer will be able to select the appropriate gases to be used for a given application, depending on the temperatures which it is desired to use.

Brief Description of The Drawings

[0019]

- Fig. 1 is a schematic representation of an apparatus, which is used to illustrate the method;
- Fig. 2 is a detailed representation of a probe, shown in cross-section;
- Fig. 3 shows the results of a heating/cooling experiment carried out with the probe of Fig. 2;
- Fig. 4 is the result of heating experiments;
- Fig. 5 schematically shows a portion of a finned tube;
- Fig. 6 is a schematic cross section of a device, the heat exchanger being shown;
- Fig. 7 schematically shows a probe;
- Fig. 8 schematically shows a probe.

Detailed Description of Preferred Embodiments

[0020] Looking now at Fig. 1, numeral 1 generally indicates a probe, comprising a heat-exchanger 2, an orifice, 3, and an isolated jacket 4, which together constitute a Joule-Thompson device. Two gas reservoirs, 5 and 6, containing gas under pressure of about 40 MPa are connected to the said heat-exchanger 2, via line 7, through one-way valves 8 and 9, and on-off valves 10 and 11. Alternatively, two compressors can be provided, to compress the gases of reservoirs 5 and 6.

[0021] When an on-off valve (10 or 11) is opened, gas flows through line 7 into heat exchanger 2, and exits orifice 3 to form a cryogen pool, indicated by numeral 12. Probe surface 13 is either cooled or heated by this pool, depending on the gas used at the time, and cools the surface of the object schematically indicated at 14, which is brought into contact with it.

[0022] The design of a probe, according to one embodiment of the invention, is more fully illustrated in

Fig. 2. An isolating sleeve 15 houses the various parts of the probe, which include a steel encapsulation 16, containing a cryocooler 17. High pressure gas is supplied through a supply line 18, and expands through an orifice (not shown). The hot or cold gas creates a pool 19, which is in contact with the heating/cooling surface 20, which is the surface used to apply cold and heat to the treated body. An additional sleeve 21 is provided for holding the cryocooler 17 in place, and the exhaust gas leaves the probe through the empty space 22 therein.

[0023] Fig. 5 schematically shows a segment of a finned tube 23 of a heat exchanger used in connection with the invention. The fins 24 are distributed along the tube. Gas at a high pressure, P1, flows within tube 23, towards orifice 25,, while exhaust gas, at a lower pressure P2, flows across the tube, as shown by the arrows.

[0024] In Fig. 6 the heat-exchanger is seen to be made of high pressure tubes 23, with fins 24, which are contained within an inner mandrel 26 and an outer mandrel 27. Gas backflowing from the cooled or heated surface 20, indicated by arrows B, flows into the heat-exchanger and comes into contact with the outer surface of the finned tube 23, thus exchanging heat with the gas flowing within it.

[0025] As stated, the invention can be exploited in a variety of medical uses. Some of the advantages obtained with the invention are:

a. Living cells destruction is more effective when operating with temperature cycles than when using cryogenic probes, as done according to the known art, which only cools the affected area.

b. Because temperature cycles are applied, the low temperature front does not penetrate too deep into healthy layers of the human body, in contrast to what happens when prior art cryogenic probes are used. Therefore, longer treatments of a superficial affected area are possible, according to the invention, while reducing the damage to healthy cells. In other words, the depth of cold front penetration is limited and controlled by the cycling frequency and, furthermore, it is independent of contact duration.

As will be appreciated by persons skilled in this art, by harmonic surface temperature profile, the depth of penetration obtained is proportional to $(\alpha \cdot \tau)^{1/2}$, α being the thermal diffusivity and τ the time period. This is known, e.g., from H. S. Carslaw and J. C. Jaeger, "Conduction of Heat in Solids", Chapter 2.6, Clavendon Press, Oxford, 1959.

c. At the end of the treatment cycle the probe can be heated to a temperature where there is no adhesion of the epidermis to the probe surface. Thus superficial damage is avoided, in contrast to what happens when attempting to remove a cool cryogenic probe from the skin.

[0026] As will be appreciated by the skilled person, probes according to the invention can be made of varying sizes for different uses, ranging from very thin probes to relatively large area probes, because the heating/cooling device can be accomodated even in very small volumes since no space-consuming parts are requires, such as electric heaters. Thus, for instance, Fig. 7 illustrates a flat, large area probe, such as may be suitable, e.g., for treatment of the epidermis or for non-medical applications. Fig. 8, on the other hand, shows a thin, pointed probe, such as may be used for penetration, e.g., into the liver for cancer therapy.

[0027] Looking at Fig. 7, and using the same numerals as in Fig. 6, for ease of understanding, the cooled and heated surface 20 is positioned near the heat-exchanger tubes 23, located between an inner mandrel 26 and an outer mandrel 27. Gas flows to the probe extremity through gas pipes located within outer sheat 28, which may contain two or more pipes, as well as electric wires, if desired. Pneumatic and electric connections can be effected, e.g., through connector 29 (the connections not being shown in detail). Flow of gases is controlled, according to this particular embodiment of the invention, through push-buttons or switches 30, positioned on the probe holder, so that the functioning of the probe is easily controlled by the user without having to shift the hand and without stopping the operation. Control lights 31 can also be provided, to indicate, e.g., when the heating or cooling gas is flowing, or when the operation of the probe has been altogether stopped.

[0028] Similarly, in Fig. 8 a thin probe is seen, in which the contact surface 20 is pointed and not flat. Because of the thinnes of the probe, the inner and outer mandrels are reduced in thickness, and are not shown for the sake of clarity. The probe holder 32, in this embodiment of the invention, can be located far from the pointed end of the probe, and can also be provided with buttons and indicating lights (not shown), as in Fig. 7.

[0029] Of course, many different shapes and sizes of probes can be provided, depending on the use for which they are intended, and the examples given above are only provided for the purpose of illustrating two of the possible different probes.

[0030] The invention will now be further illustrated through the following examples.

__Example 1__

__Heating-Cooling Cycles__

[0031] The device described above was used in an experiment in which heating-cooling cycles were generated, and the temperature obtained at the surface (13) of the probe was recorded. The diameter of the heat-exchanger exchanger (2) was 5.2 mm, and it was kept under vacuum in excess of 100 Pa. The diameter of the orifice was 0.12 mm.

[0032] Helium at 68.9 MPa (10,000 psi) was employed. Nitrogen was at 42.4 MPa (6000 psi) and its flow rate was about 3 standard m^3/h (50 SLPM.)

[0033] Heating was effected from room temperature, until a temperature of 120°C was reached, after which the gas was changed and the probe was allowed to cool down to -190°C. The cooling and the heating times were almost the same, and the total cycle took about 30 seconds. This, as will be appreciated by the skilled person, is a surprisingly short time for such a cycle, which can hardly be obtained with prior art devices. The results are shown in Fig. 3.

__Example 2__

__Heating Experiment__

[0034] The same probe as in Example 1 was tested for fast heating. Under the same conditions as described with reference to Example 1, the probe was allowed to heat up to 170°C. The result is shown in Fig. 4, from which it can be seen that heating from room temperature to 170°C was achieved in 6.5 seconds. This result illustrates the effect of the inversion temperature, and proves that heating can be obtained using helium. The experiment was also repeated with a temperature limit of 205°C, and comparable results were obtained, with a heating time of 12 seconds.

[0035] All the above description and examples have been provided for the purpose of illustration, and are not intended to limit the invention in any way. Likewise different gas pairs and gas mixtures can be used, and different low and high temperatures exploited, all without exceeding the scope of the invention, which is defined by the present claims.

Claims

1. A method for creating a surface (14) having a fast changing temperature, comprising providing a heat exchanger (2) coupled to an orifice (3) opening into a jacket (4) which is in contact with the surface (14) to be heated and cooled, said jacket (4) forming a reservoir capable of housing a fluid in contact with the surface (14) to be heated and cooled, and providing two gas sources (5,6), each gas source being independently connected to said heat exchanger (2), one source providing a first gas, which liquefies when it expands through said orifice (3), and the other gas source providing a second gas, having an inversion temperature lower than the temperature obtained by the liquefaction of the first gas, and causing the exhaust gas flowing out from said jacket (4), to flow through said heat-exchanger (2) to preheat or precool the inflowing gas, as the case may be, and further causing said first and said second gas repeatedly and alternately to flow through said heat exchanger and orifice, to cool or to heat said surface with a plurality of heating-cooling cycles; means (10, 11, 8, 9) being provided for repeatedly and alternately allowing and stopping the flow of each gas through the said orifice.

2. A method according to claim 1, wherein said heating-cooling cycles are periodic.

3. A method according to claim 1, wherein the fast change is controlled and effected at the time selected by the operator.

4. A method according to any one of claims 1 to 3, wherein the first gas is selected from the group consisting essentially of argon, nitrogen, air, krypton, CF_4, xenon and N_2O, and the second gas is helium.

Patentansprüche

1. Verfahren zum Erzeugen einer Oberfläche (14) mit einer sich schnell ändernden Temperatur, umfassend:

   Bereitstellen eines Wärmetauschers (2), der mit einer Öffnung (3) gekoppelt ist, die sich in eine Ummantelung (4) öffnet, welche in Kontakt mit der zu erwärmenden und abzukühlenden Oberfläche (14) steht, wobei die Ummantelung (4) ein Reservoir bildet, das ein Fluid in Kontakt mit der zu erwärmenden und abzukühlenden Oberfläche (14) aufnehmen kann, und
   Bereitstellen zweier Gasquellen (5,6), wobei jede Gasquelle unabhängig mit dem Wärmetauscher (2) verbunden ist und eine Quelle ein erstes Gas liefert, welches sich verflüssigt, wenn es durch die Öffnung (3) expandiert, und die andere Gasquelle ein zweites Gas liefert, das eine Umkehrtemperatur aufweist, welche niedriger ist als die durch das Verflüssigen des ersten Gases erhaltene Temperatur, sowie
   Veranlassen, daß das aus der Ummantelung (4) ausströmende Abgas durch den Wärmetauscher (2) strömt, um das einströmende Gas je nach Fall vorzuwärmen oder vorzukühlen, und ferner
   Veranlassen, daß das erste und das zweite Gas wiederholt und alternierend durch den Wärmetauscher und die Öffnung strömen, um die Oberfläche mit einer Mehrzahl von Erwärmungs-Abkühlungszyklen abzukühlen oder zu erwärmen, wobei eine Einrichtung (10,11,8,9) vorgesehen ist, um das Strömen jedes Gases durch die Öffnung wiederholt und alternierend zu gestatten und zu stoppen.

2. Verfahren gemäß Anspruch 1, wobei die Erwärmungs-Abkühlungszyklen periodisch sind.

3. Verfahren gemäß Anspruch 1, wobei die schnelle Änderung zu der durch die Bedienungsperson gewählten Zeit gesteuert und ausgeführt wird.

4. Verfahren gemäß einem der Ansprüche 1 bis 3, wobei das erste Gas aus der Gruppe gewählt ist, die im wesentlichen aus Argon, Stickstoff, Luft, Krypton, CF_4, Xenon und N_2O besteht, und das zweite Gas Helium ist.

Revendications

1. Procédé de création d'une surface (14) présentant une température à variation rapide, comprenant la mise en place d'un échangeur de chaleur (2) couplé à un orifice (3) débouchant dans une enveloppe (4) qui se trouve au contact de la surface (14) devant être chauffée et refroidie, la dite enveloppe (4) formant un réservoir capable de recevoir un fluide en contact avec la surface (14) devant être chauffée et refroidie, et la mise en place de deux sources de gaz (5, 6), chaque source de gaz étant indépendamment raccordée au dit échangeur de chaleur (2), une première source de gaz fournissant un premier gaz qui se liquéfie en traversant le dit orifice (3), et l'autre source de gaz fournissant un second gaz présentant une température d'inversion inférieure à la température obtenue par la liquéfaction du premier gaz, et amenant le gaz d'évacuation qui s'écoule et sort de ladite enveloppe (4) à s'écouler en traversant le dit échangeur de chaleur (2) de manière, selon le cas, à préchauffer ou à pré-refroidir le gaz entrant, et à amener, en outre, le dit premier et le dit second gaz, de façon répétitive et alternée, à s'écouler en traversant les dits échangeur de chaleur et orifice afin de refroidir ou de chauffer la dite surface au cours d'une pluralité de cycles de chauffage et de refroidissement ; des moyens (10, 11, 8, 9) étant prévus pour autoriser et interrompre, de façon répétitive et alternée, l'écoulement de chaque gaz au travers du dit orifice.

2. Procédé selon la revendication 1, dans lequel les dits cycles de chauffage et de refroidissement sont périodiques.

3. Procédé selon la revendication 1, dans lequel la variation rapide est commandée et s effectue à l'instant sélectionné par l'opérateur.

4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel le premier gaz est sélectionné parmi le groupe constitué essentiellement d'argon, d'azote, d'air, de krypton, de CF_4, de xénon et de N_2O, et le second gaz est de l'hélium.

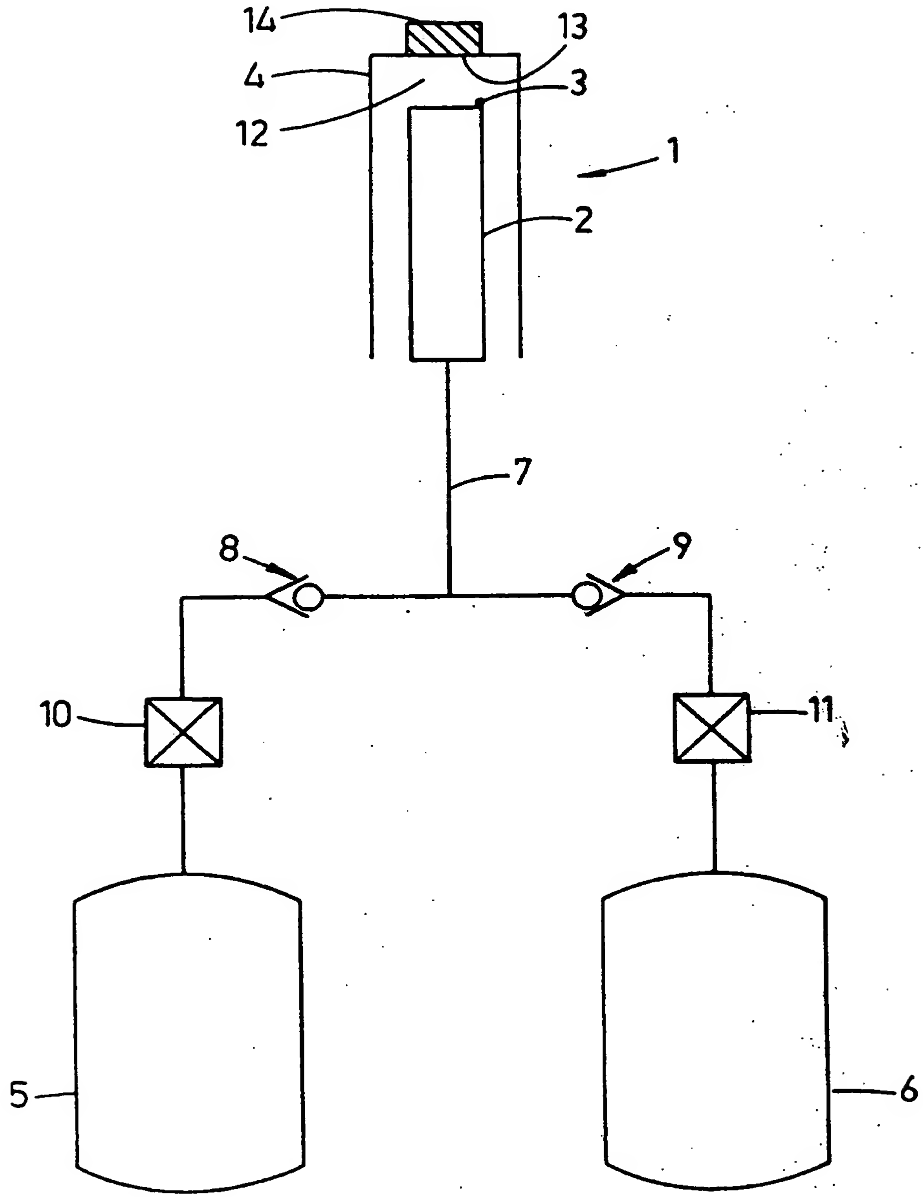

Fig. 1

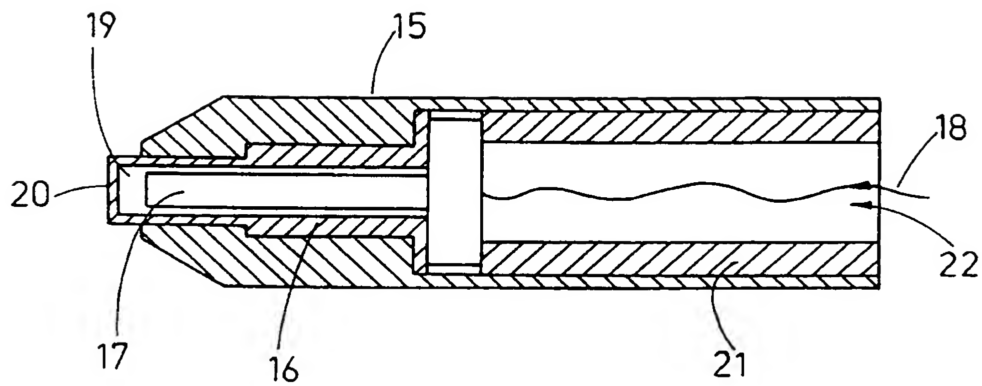

Fig. 2

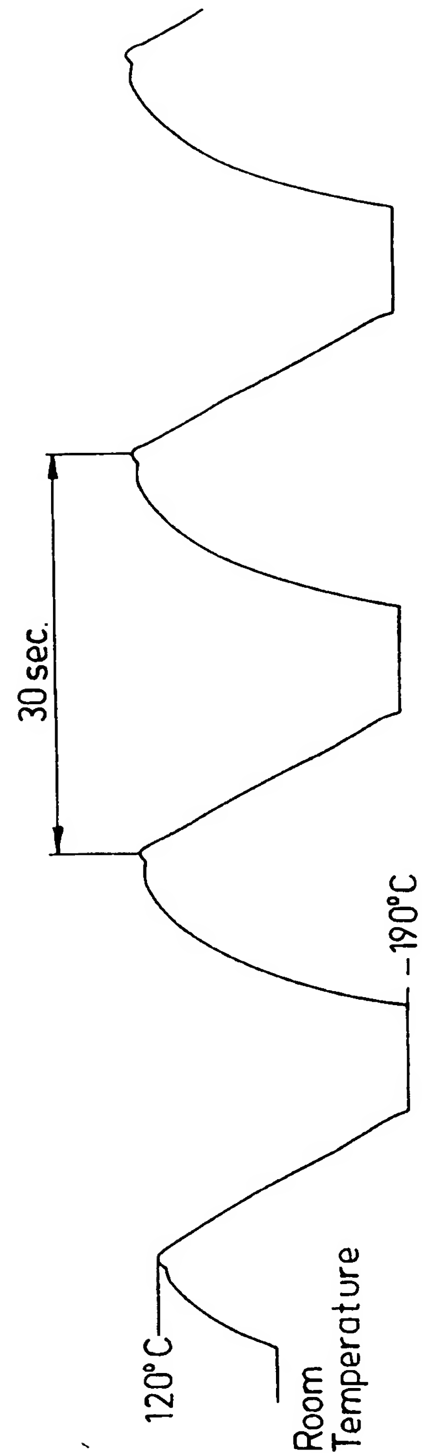

Fig. 3

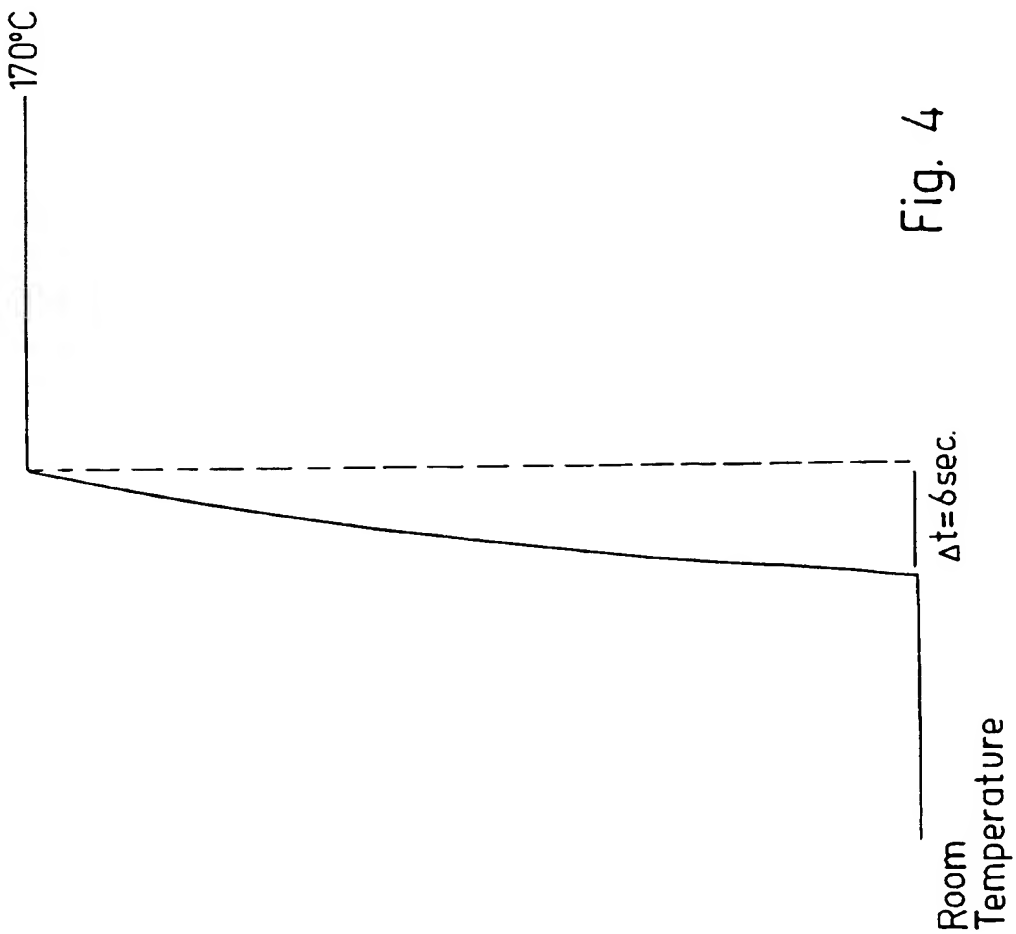

Fig. 4

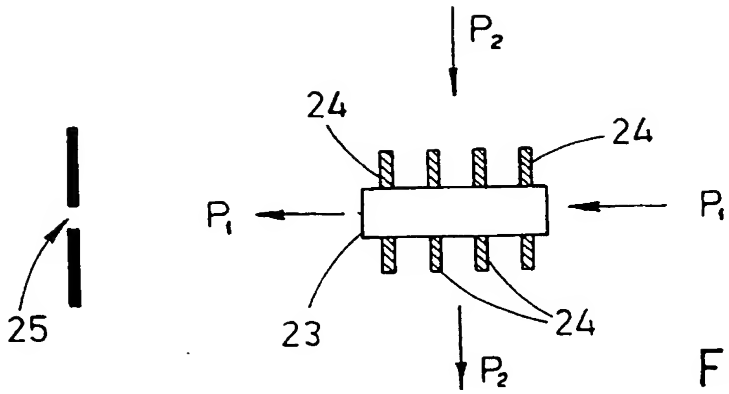

Fig. 5

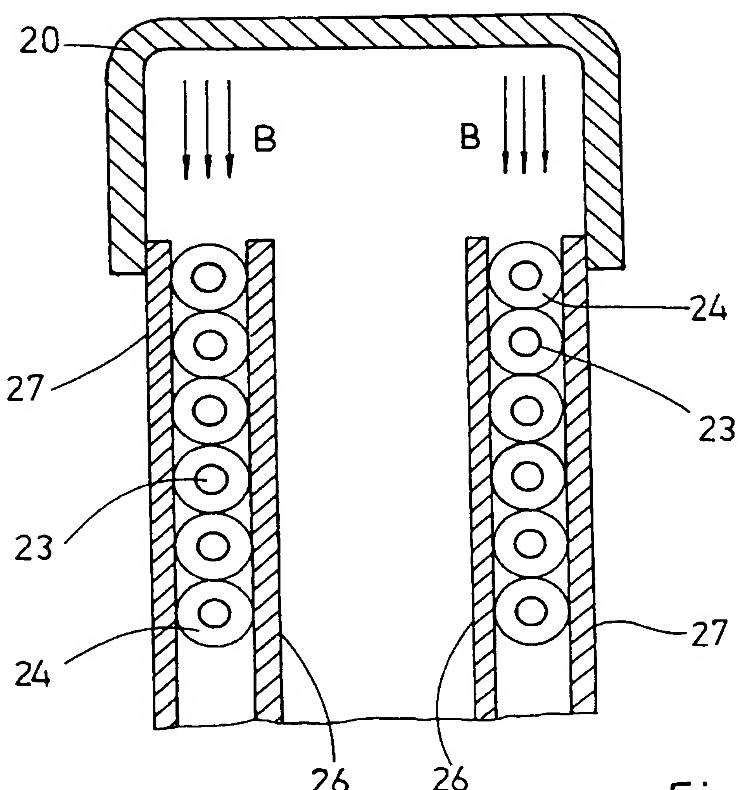

Fig. 6

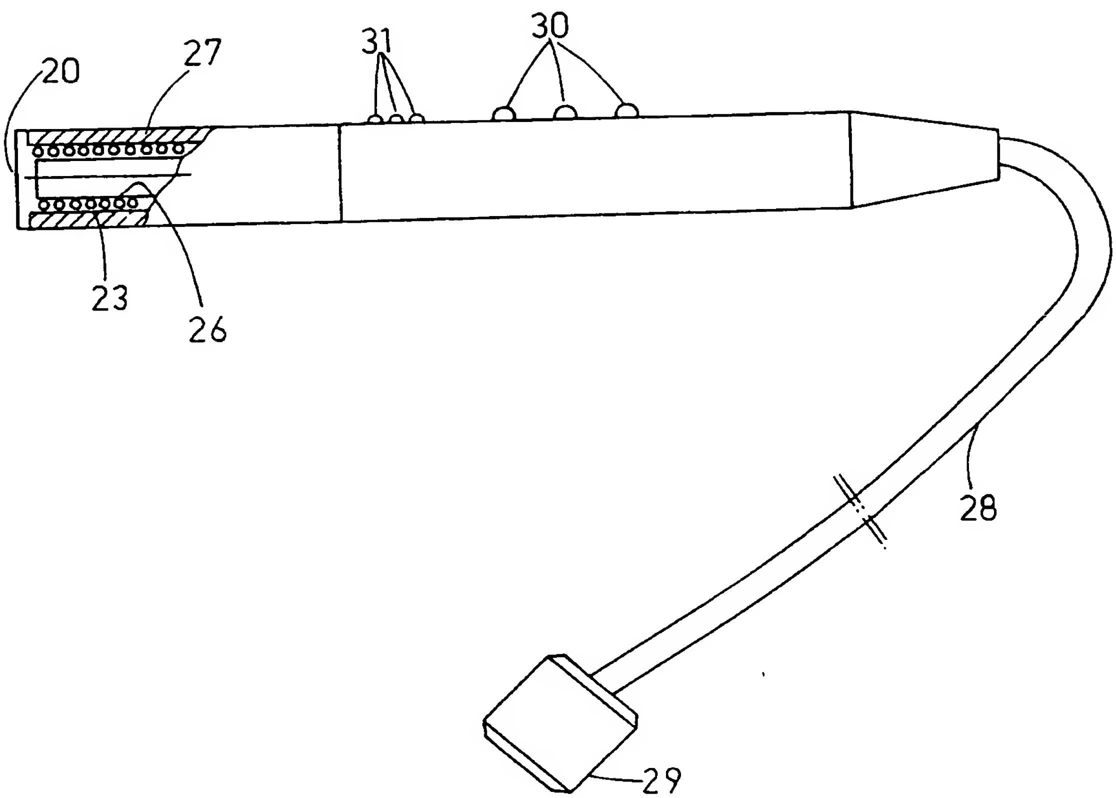

Fig. 7

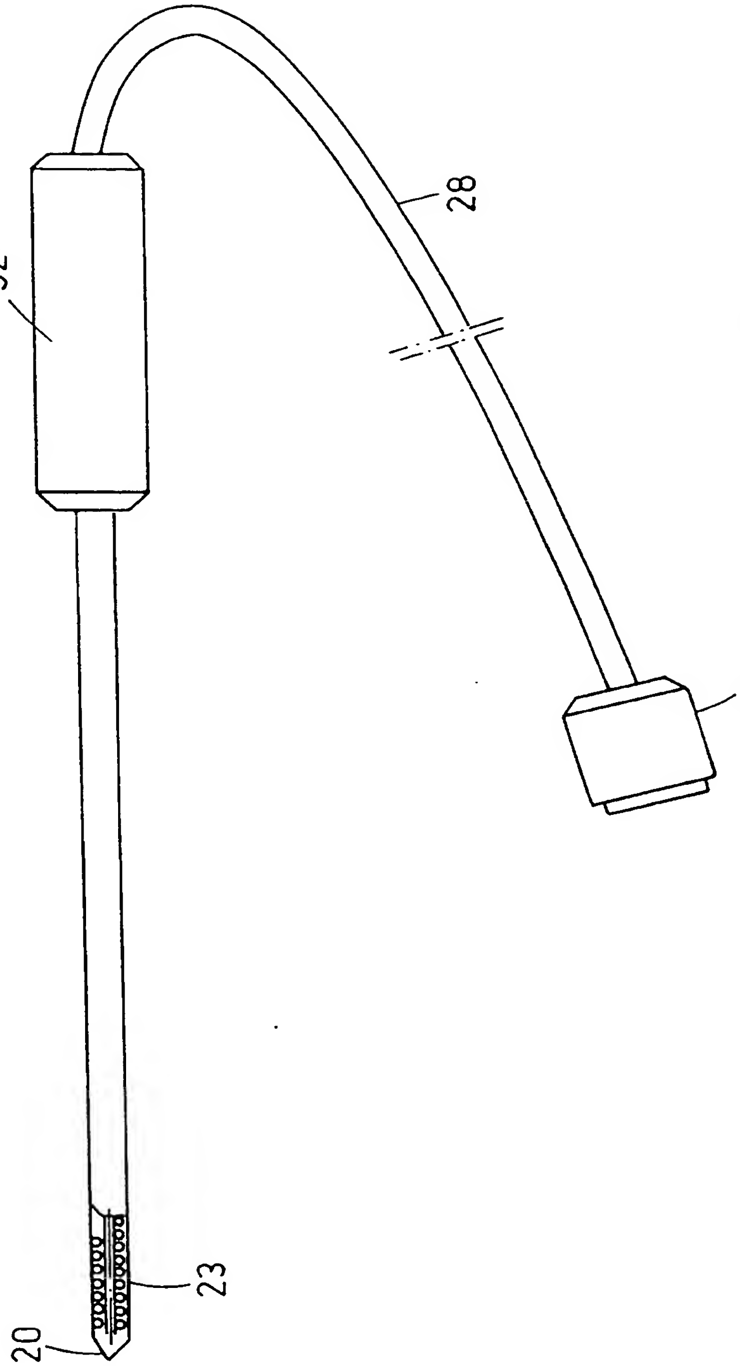

Fig. 8